MEASUREMENTS OF HAZEMEYER PRECISION TRANSDUCTORS

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Two different types of Hazemeyer high precision, bipolar transductors have been received and evaluated. Both transductors or DCCT's operate on the zero flux second harmonic principle.* One unit rated at ±100A (specification EM-9.293.233-U, high precision) was purchased by Fermilab; the other unit rated at ±50A (specification EM-291.611-U) was loaned to Fermilab by Brookhaven National Laboratory. The specifications for these units, given on the following pages, are similar; however, the physical size, performance, and cost of the two units are different. The two transductors are shown in Fig. 1. The Fermilab DCCT is a self-contained unit with a separate transformer and the Brookhaven unit has a larger electronics package with a separate DCCT head (chassis #A20BP126, burden resistor #A405, core assembly #A-50-20-09-78-267). These lower current transductors have been evaluated for use in the Energy Doubler/Saver correction element system. Hazemeyer makes other higher current units based on the Brookhaven design which are of interest for other accelerator applications.

TRANSDUCTOR EVALUATION

For brevity the Fermi unit is called DCCT2 and the Brookhaven unit is called DCCT1 in the following pages. A simple comparison of

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*"Zero-Flux Current Transformers for Precise Measurement of Direct Current," internal report by Hazemeyer, a member of the Holec group of companies; Henglo, Holland.

SPECIFICATION

Nat. Acc. Lab. U.S.A.
EM-9.293.223-U

		High Precision	Economy	
Nominal primary current I_n	:	+ & - 50	+ & - 50	A
Test voltage, 50 Hz, 1 min.	:	2500	2500	V_{rms}
Output voltage at I_n	:	+ & - 10	+ & - 10	V
Max. output current	:	+ & - 2	+ & - 2	mA
Output impedance	:	1	10	mΩ
Bandwidth, small signal	:	10	10	kHz
Slewing rate	:	25	25	V/ms
Output ripple voltage	:	10	100	ppm of F.S.
Ratio error				
- initial	:	100	500	ppm
- vs temperature	:	1	5	ppm/^{o}c
- vs time	:	1	1	ppm/month
Offset error				
- initial	:	10	50	ppm of F.S.
- vs temperature	:	1	5	ppm of F.S./^{o}C
- vs time	:	1	1	ppm of F.S./month
Linearity error	:	5	25	ppm
Operating temperature range	:	0-40	0-40	^{o}C
Dimensions (approx)				
- length	:	180	180	mm
- width	:	180	180	mm
- height	:	100	100	mm
- diameter feed-through hole	:	15	15	mm
Supply voltage (50/60 Hz)	:	115	115	V_{rms}
Power consumption	:	10	10	VA

Our ref.: EM-291.611-U

Crate	:		
Assembly	:		
Burden	:		
Type	:	A/Bipolar	
Nominal primary current I_n	:	± 50	A
Max. primary r.m.s. current	:	50	A
Overload current	:	10	I_n
Test voltage, 50 Hz, 1 min	:	2,5	kV
Output voltage at I_n	:	±10	V
Max. output current	:	± 2	mA
Output impedance	:	1	mOhm
Bandwidth, small signal	:	10	kHz
Slew rate	:	25	V/ms
Noise voltage r.m.s.	:	10	ppm of F.S.
Ratio error			
- initial	:	100	ppm
- vs. temperature	:	1	ppm/ °C
- vs. time	:	1	ppm/ month
Offset error			
- initial	:	10	ppm of F.S.
- vs. temperature	:	1	ppm of F.S./°C
- vs. time	:	1	ppm of F.S./mo.
Linearity error	:	5	ppm
Warming-up time	:	nil	
Max. ambient temperature			
- module	:	40	°C
- Core assy	:	55	°C
Dimensions core and coil assembly			
- ϕ	:	100	mm
- W	:	80	mm
- $\emptyset$	:	27	mm
- r	:	100	mm
- l	:	100	mm
Cable length	:	2,5	m
Induced voltage in primary circuit	:	15	mV peak
Height of module	:	2	x 1 3/4 inch
Power consumption	:	50	VA
Supply voltage	:	120	V, 60Hz - 1p

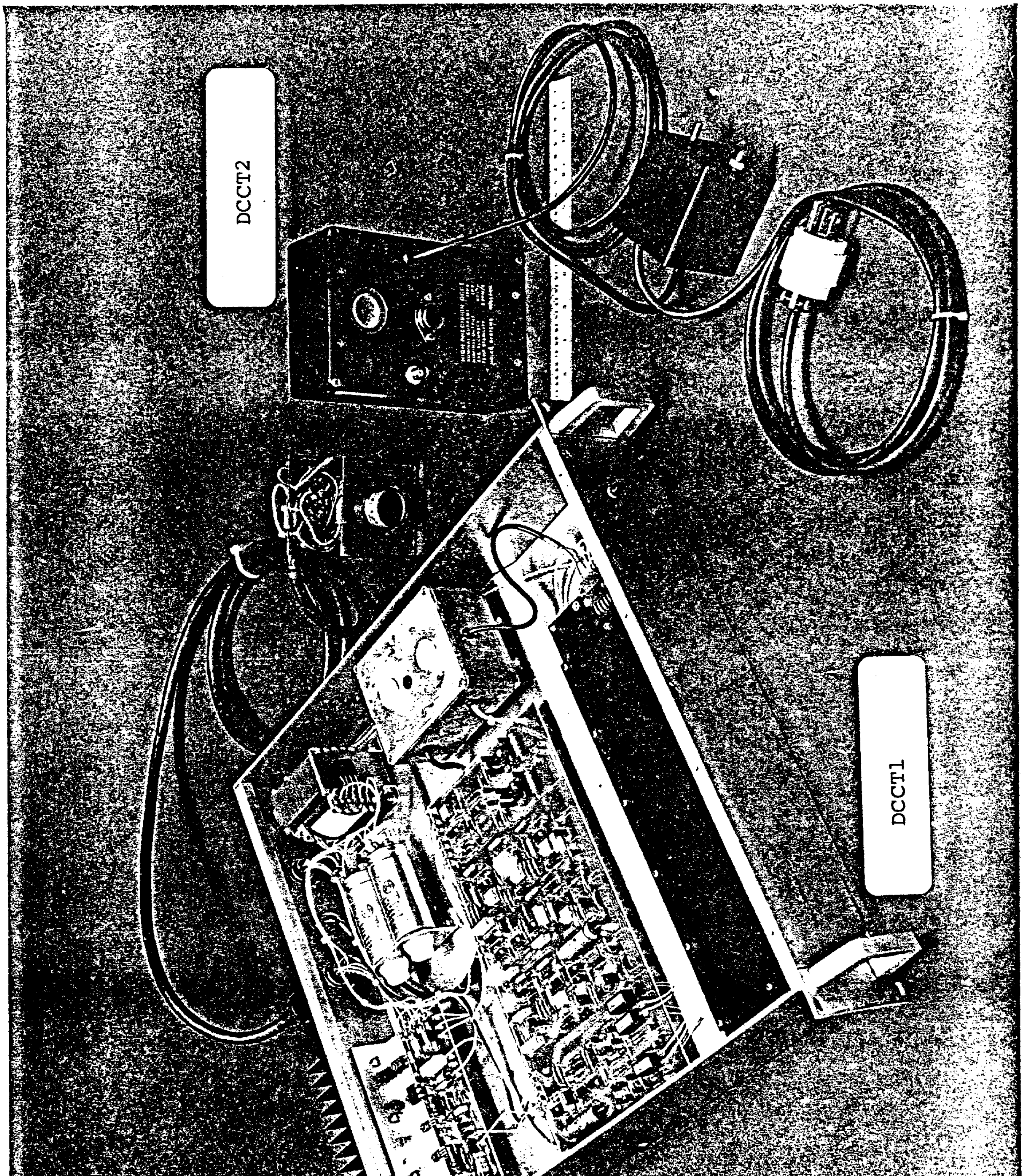


FIGURE 1 - HAZEMEYER PRECISION TRANSDUCTORS

the specifications for the DCCT's is misleading as is found by examining the output ripple voltage of each unit.

Output Ripple Voltage: Both DCCT's have an output ripple specification of 10 ppm rms of full scale. Measurements of ripple with a true rms meter gives 19 ppm ripple for DCCT2 which is out of specification. However, output ripple photographs give a more accurate picture of transductor output quality. Figure 2 shows higher frequency ripple for the transductors with different scope bandwidth settings and gain settings. Obviously, DCCT2 has much worse output noise ripple even with a 100 Hz filter. (Notice the fundamental output ripple frequency is 50 Hz.) Figure 2 also shows low frequency noise of DCCT1. This low frequency or popcorn noise amounting to about 50 μV peak to peak is not mentioned in specifications sheet.

Induced Voltage in Primary Circuit: The induced voltage specification for DCCT1 is 15 mV peak; there is not a similar specification for DCCT2. Figure 3 shows the induced voltage in a single turn through each transductor. The induced voltage in DCCT2 is quite small compared to the 26 mV peak to peak voltage for DCCT1. The induced voltage generates a ripple current in the load, dependent on the impedance of the load circuit. In high precision, low bandwidth circuits the induced voltage could be a problem. The high induced voltage of DCCT1 caused problems in the test set-up shown in Fig. 4, for measuring linearity and ratio errors. A 50 turn coil of wire with taps at every five turns was passed through each of the transductors. To eliminate linearity errors and reduce drift errors caused by the current calibrator, the calibrator was run at a constant 1.00000A. To

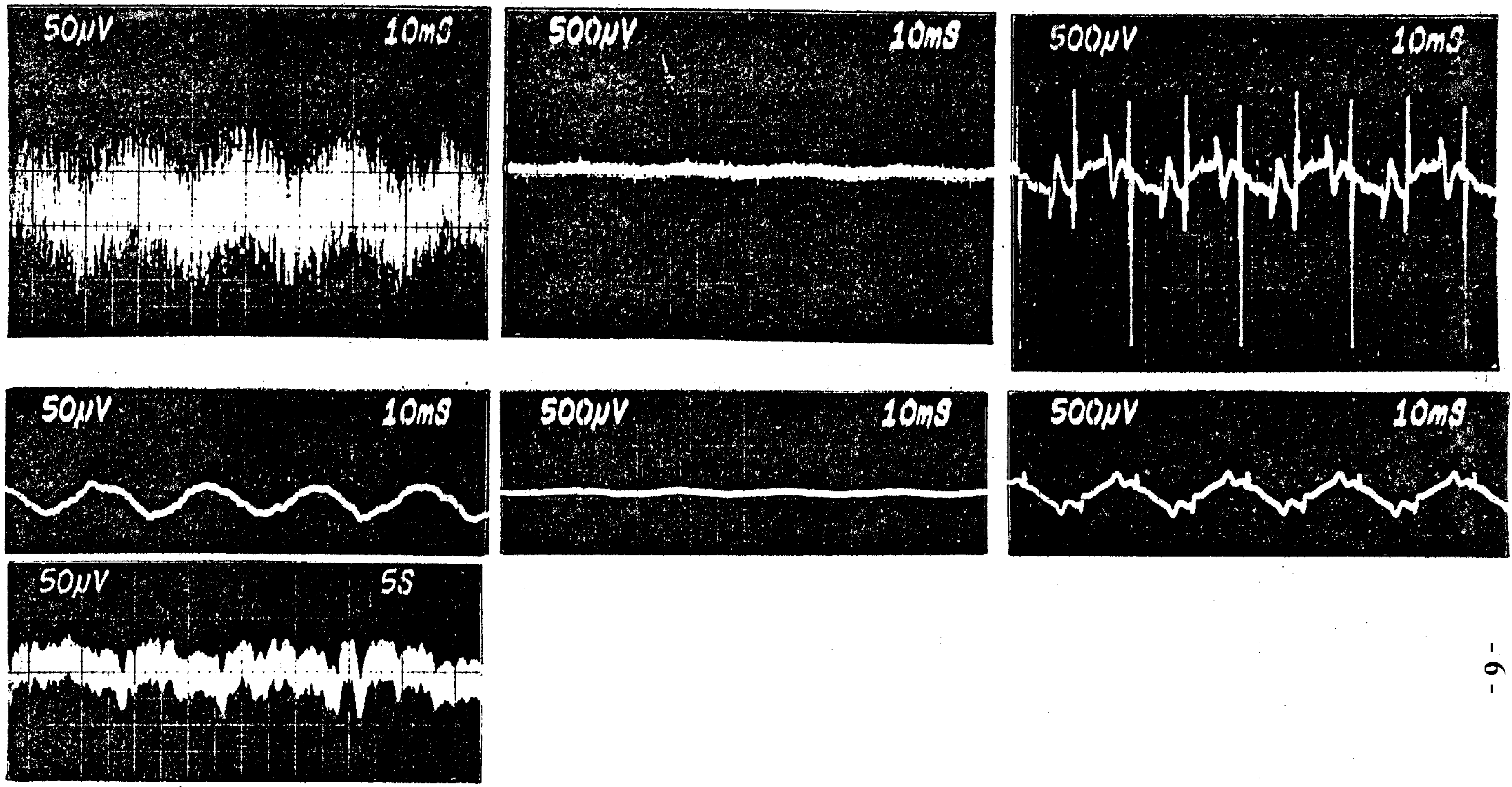


FIGURE 2 - TRANSDUCTOR OUTPUT NOISE

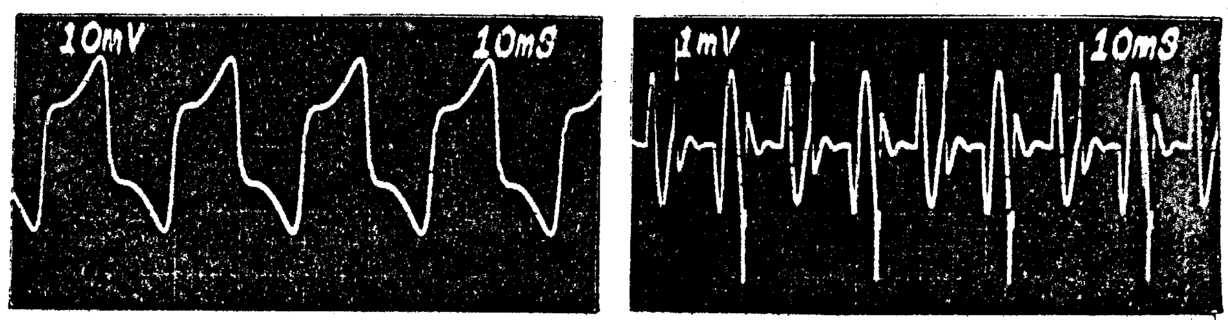


FIGURE 3 - INDUCED VOLTA   IN PRIMARY CIRCUIT

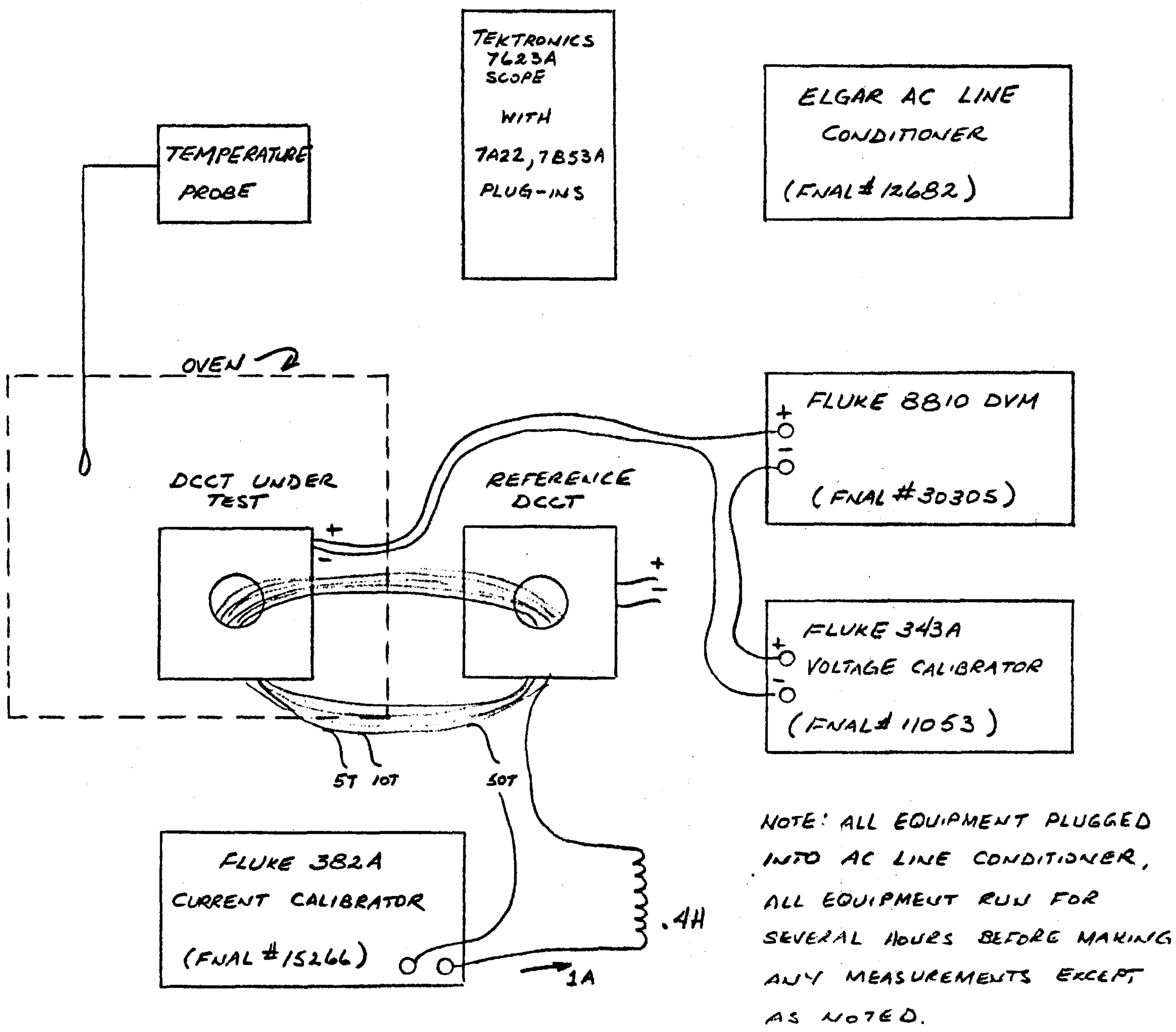


FIGURE 4 - DCCT TEST SET-UP

change current through the DCCT's, different coil taps were used. Each turn of wire through the DCCT had an induced voltage which added together and appeared across a .4H load. The resultant ripple current which then flowed was again multiplied by the number of turns through the transductor to produce a ripple voltage in the DCCT output. The ripple for DCCT1 with 50 turns was large and led to some uncertainty in measurements as indicated in the next section.

Linearity Error: The linearity error for both DCCT's is specified as ±5 ppm of reading. Figure 4 shows the set-up used to measure linearity. The output of the DCCT under test was bucked-out by the Fluke voltage calibrator and the resultant signal nulled on the Fluke dual slope integrating DVM to reduce ripple effects. Of course, the measured DCCT linearity is dependent on the voltage calibrator linearity. Although the calibrator linearity is not specified or guaranteed, the factory said that the 343A calibrator is typically linear to ±2 ppm. One problem was found with this test set-up initially for DCCT1. The precision output amplifier in DCCT1 could not drive capacitive loads larger than about 1000 pf without oscillating. Capacitor C66 (.1 μfd) had to be removed in the Fluke 343A in order to make useful measurements. The capacitive loading problem did not appear in DCCT2.

Linearity checks for both transductors were made at 21°C and 40°C. Within the measurement accuracies which were obtainable, both transductors were linear to ±5 ppm at both temperatures. Figures 5 and 6 show typical data obtained with measurement uncertainties due to reading the DVM. (DCCT1 had larger uncertainties due to larger induced current ripple.) DCCT2 was also tested to ±100A at 21°C and found to be within

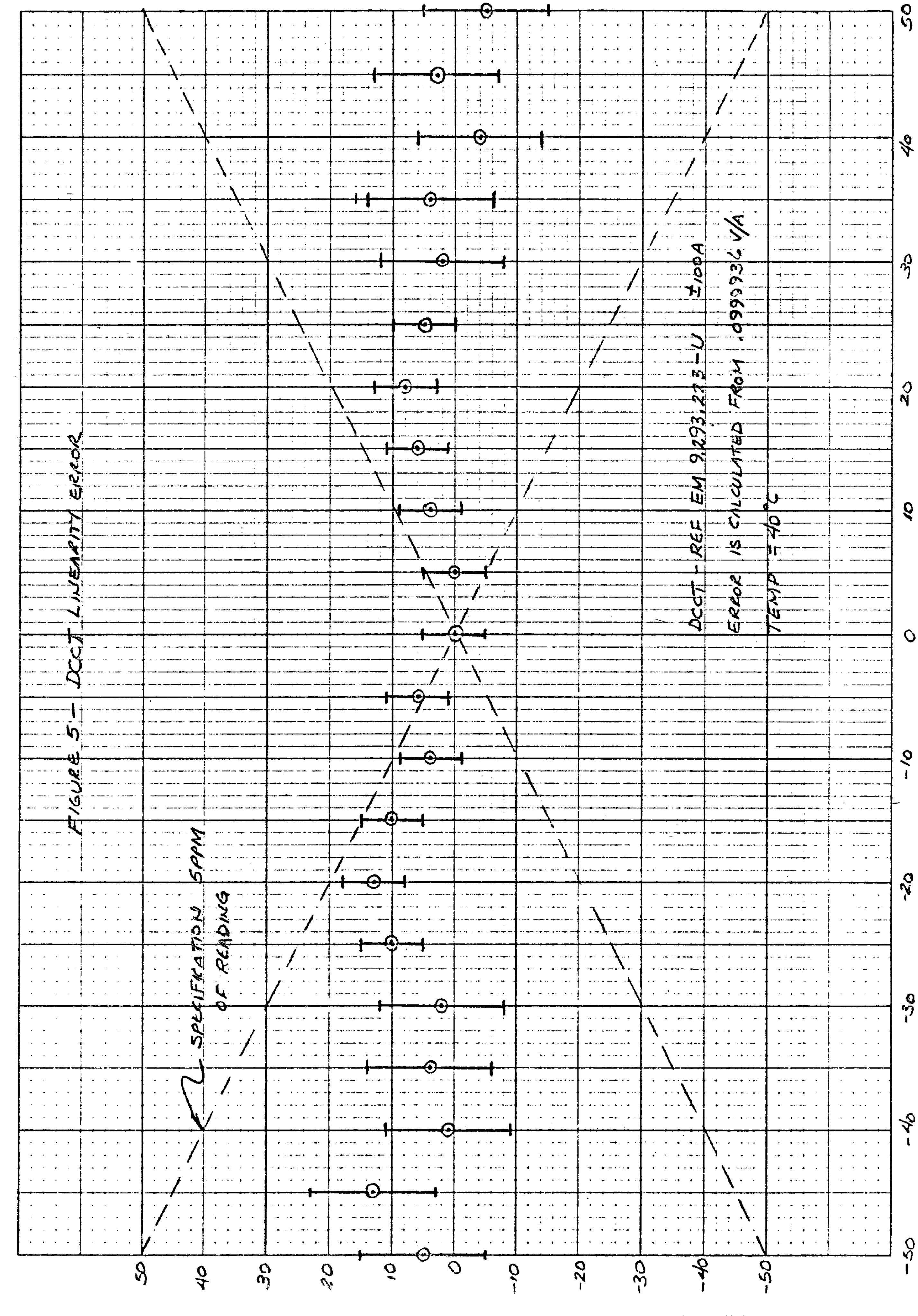


FIGURE 5 - DCCT LINEARITY ERROR
SPECIFICATION 5PPM
OF READING
DCCT - REF EM 9,293,223-U ±100A
ERROR IS CALCULATED FROM .0999936 V/A
TEMP = 40°C
50
40
30
20
10
0
-10
-20
-30
-40
-50

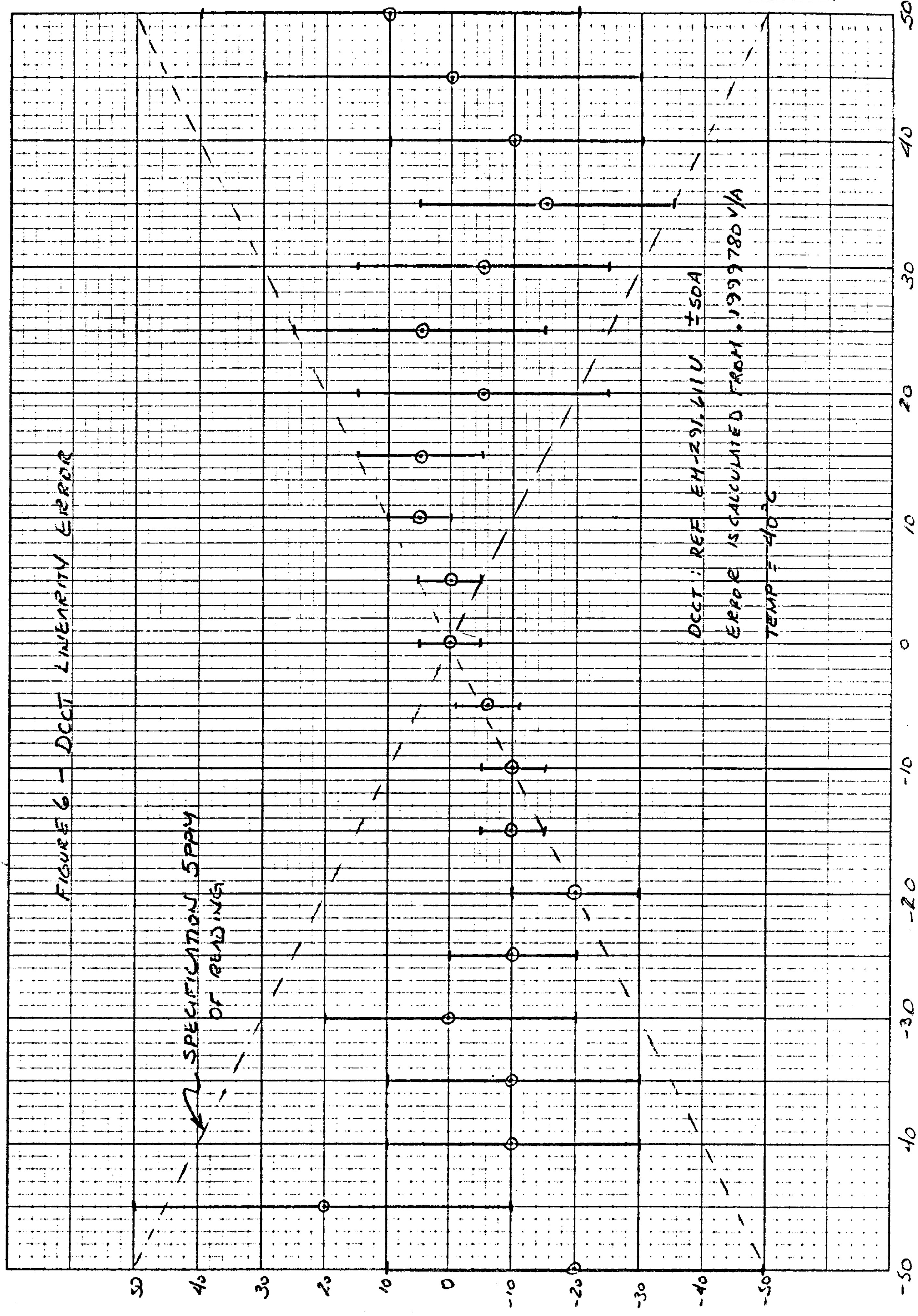


FIGURE 6 – DCCT LINEARITY ERROR
SPECIFICATION 5PPM OF READING
DCCT: REF EH-291.411U ±50A
ERROR IS CALCULATED FROM .1999780 V/A
TEMP = 40°C
50
40
30
20
10
0
-10
-20
-30
-40
-50
50
40
30
20
10
0
-10
-20
-30
-40
-50

±5 ppm.

Ratio or Gain Error: Both transductors have an initial ratio error specification of 100 ppm. The fluke 343A which has a specified accuracy of ±200 ppm was used as a reference to check initial ratio. DCCT1 was found to have a ratio error of -34 ppm, ±200 ppm and DCCT2 had a ratio error of -23 ppm, ±200 ppm. The printed temperature dependence of ratio error is ±1 ppm/°C for both devices. However, the Fermi transductor, DCCT2, was received with a label giving a specification of ±2 ppm/°K. Both transductors were checked against each other with the set-up in Fig. 4. The average of several test runs at 21°C and 40°C gave the following performance results: DCCT1, -2.1 ppm/°C; DCCT2, +.8 ppm/°C. It should be noted that the Brookhaven unit, DCCT1, did not meet its specification while the other transductor was better than specified.

Offset Error: The transductors both have an offset voltage versus time specification of ±1 ppm of full scale per month. DCCT1 indicates that no warm-up time is required. Tests show; however, that both transductors have an offset warm-up characteristic. Different test runs gave somewhat different results but the curves shown in Fig. 7 are typical of what was found. A change of 10 μV represents 1 ppm of full scale. For maximum stability, the transductors should be on for at least an hour before using them.

Initial offset voltage measured for the transductors was the steady-state value reached in Fig. 7. Both transductors have a specification of ±10 ppm of full scale. DCCT2 was found to have an initial offset of +5.5 ppm while DCCT1 had an offset which varied for no apparent reason between 0 and 8 ppm. Most of the time the initial offset for DCCT1 was around 5 ppm.

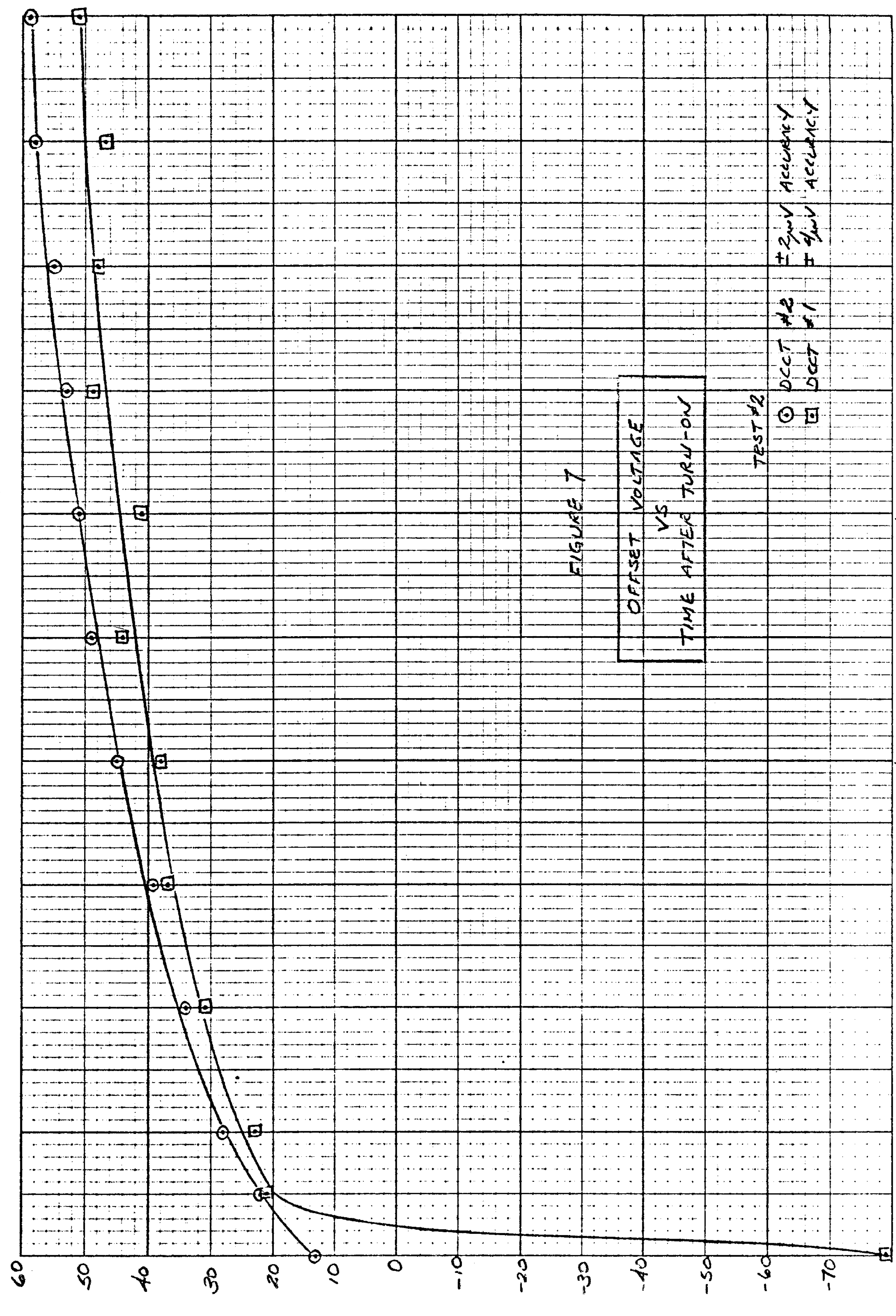


FIGURE 7
OFFSET VOLTAGE
VS
TIME AFTER TURN-ON
TEST #2
DCCT #2 ± 2mV ACCURACY
DCCT #1 ± 4mV ACCURACY
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-70
0
10
20
30
40
50
60
70
80
90
100

Offset error voltage versus temperature was also measured. Both transductors have a specification of ±1 ppm of full scale/°C. DCCT2 had a very good temperature offset characteristic of -.06 ppm/°C while DCCT1 had a temperature dependence of +.31 ppm/°C as measured between 21°C and 40°C.

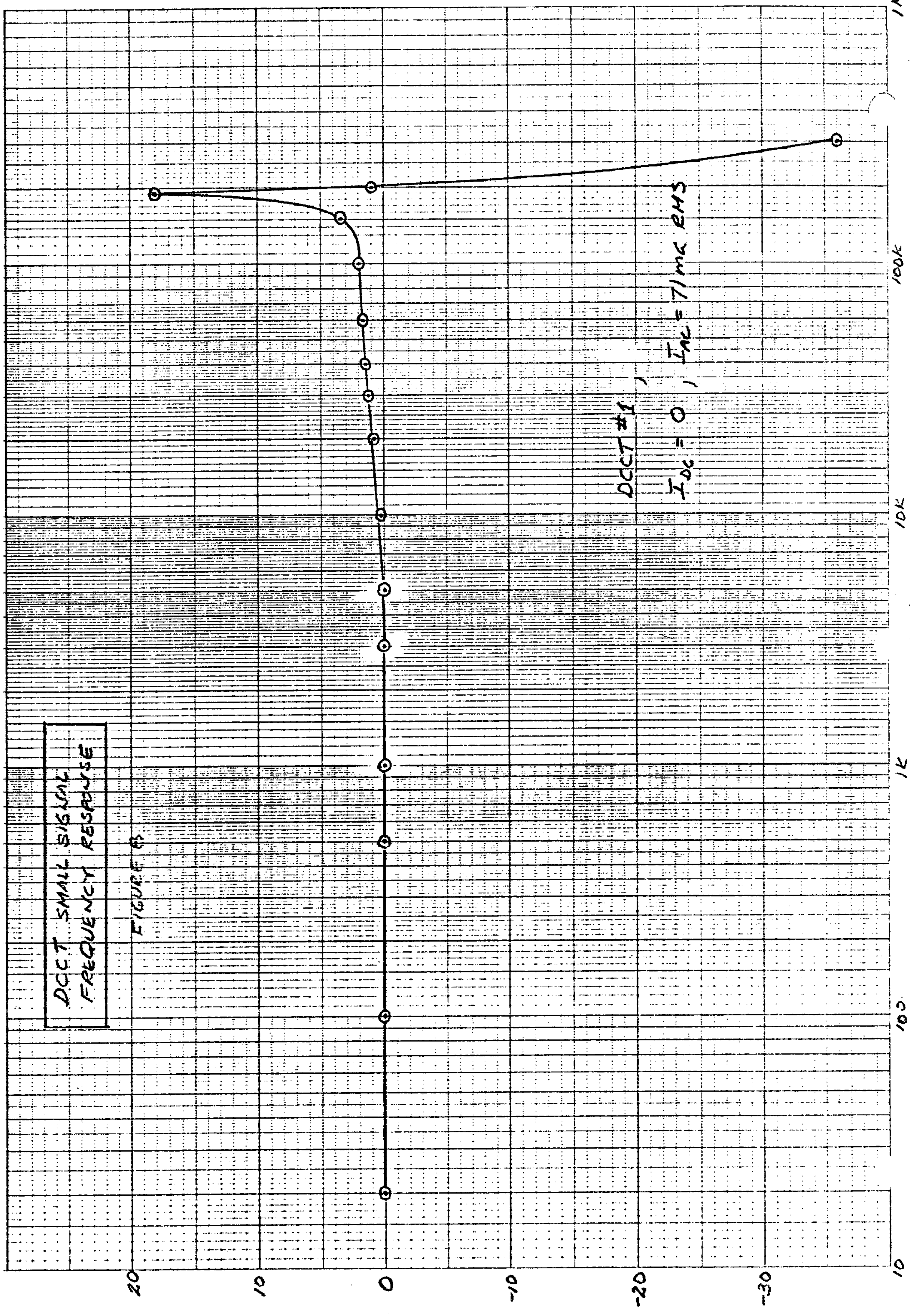
Small Signal Bandwidth: Each of the transductors have a small signal bandwidth specification of 10 kHz. The gain versus frequency for each transductor was measured at 0 and 25 Adc and found to be the same. The small signal gain at 25 Adc was measured with separate ac and dc wires through the transductor. Figure 8 shows the normalized frequency response for DCCT1 and Fig. 9 shows the normalized response for DCCT2. As can be seen, both transductors have a frequency response that is essentially flat (±2%) to 10 kHz. A sharp resonance occurs at 189 kHz but that is well beyond the frequency at which the tranductors are normally used.

Line Change: The input ac line voltage was varied from 80V to 130V. As could be expected there was no measurable (less than 2 ppm) difference in transductor output voltage of either unit.

DISCUSSION

While the two transductors measured have similar specifications, the units perform differently. DCCT2 has a very noisy output, particularly when compared to DCCT1. A noisy DCCT output tends to introduce ripple into any power supply in which it is used just as would a noisy reference signal.

DCCT1 does not seem to be as stable as DCCT2 which is the reverse of what you would expect from the manufacturers specifications. Also


DCCT SMALL SIGNAL
FREQUENCY RESPONSE
FIGURE 8
DCCT #1,
$I_{DC} = 0$, $I_{AC} = 71$ mA RMS
20
10
0
-10
-20
-30
10
100
1K
10K
100K
1M

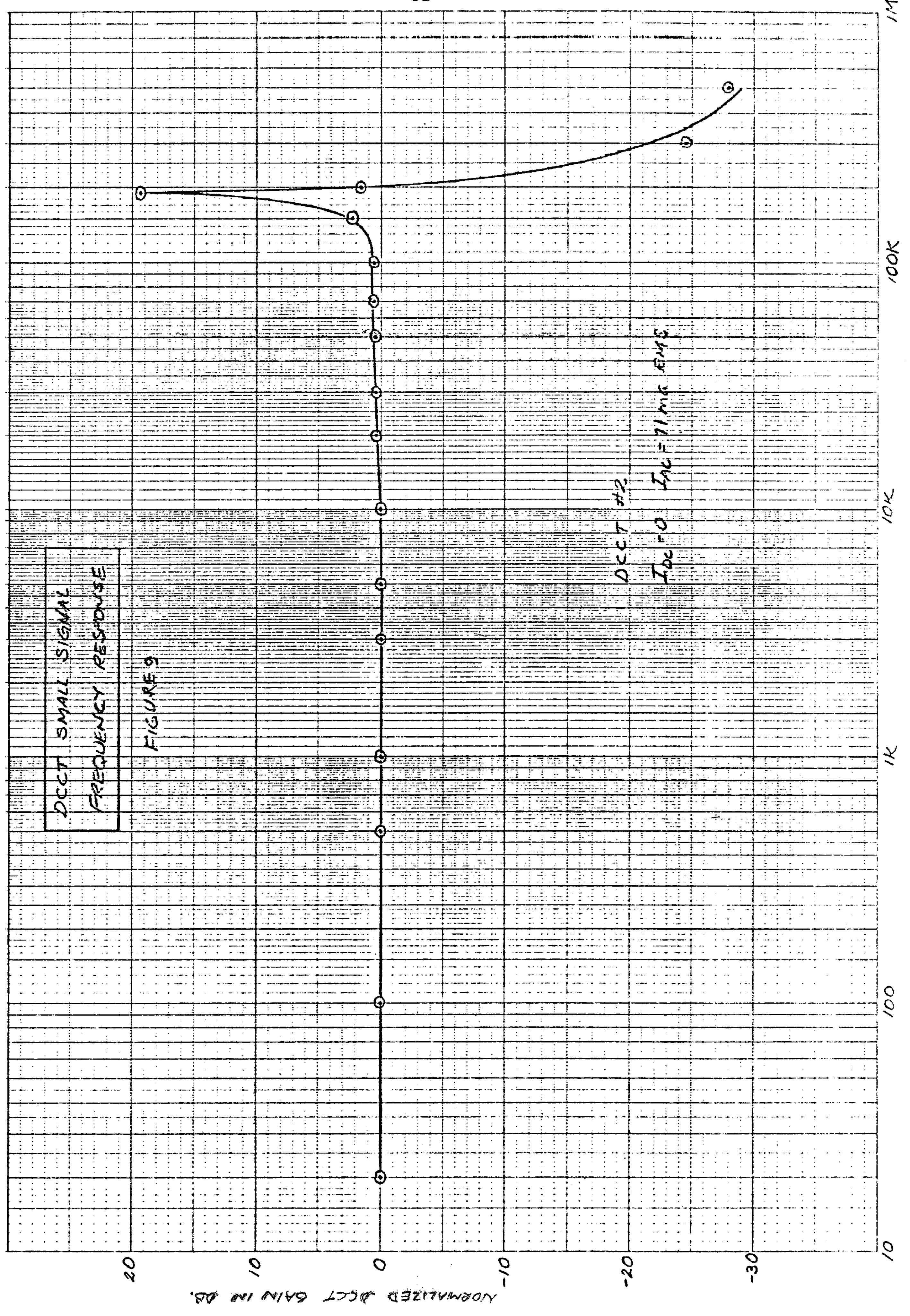

DCCT SMALL SIGNAL
FREQUENCY RESPONSE
DCCT #2
$I_{DC}=0$ $I_{AC}=71$ MA RMS
20
10
0
-10
-20
-30
NORMALIZED DCCT GAIN IN DB.
10
100
1K
10K
100K
1M

FIGURE 9

both transducters exhibit a warm-up characteristic not mentioned by the manufacturer. Finally, it should be pointed out that the primary circuit induced voltage is much higher in DCCT1 than DCCT2. The higher induced voltage could conceivably introduce some ripple current into the load circuit which would be undesirable.

Hazemeyer in Henglo, Holland was contacted regarding the above performance tests. Hazemeyer contends that the Brookhaven unit, DCCT1, should have a better temperature ratio coefficient than DCCT2, contrary to what was measured. They also felt that the offset of DCCT1 should be more stable than we measured. They felt the problem could be in a bad precision output amplifier (V1). Hazemeyer was also surprised at the magnitude of the low frequency popcorn noise shown in Fig. 2 for DCCT1. They said the problem was most likely due to a noisy LM308 amplifier (V46) which drives the power amplifier which feeds the burden resistor. Amplifier V46 was changed to a low noise OP-05 device; however, no improvement was seen in the DCCT's low frequency noise output. Finally, Hazemeyer said that DCCT2 inherently has a higher output noise voltage than DCCT1 which has a more elaborate filtering scheme.